Gail Purvis

'Poland' may not be the normal instinctive response on hearing the words 'electronics industry'. But, in a determined and very pragmatic fashion, the homeland of Jan Czochralski and his single-crystal growth method has set out to make its mark as a significant electronics location in Europe. While it is already an acknowledged source of highly skilled analogue engineers, the Warsaw-Poznan-Gdansk triangle is home to a small but nicely balanced infrastructure for a growing electronics industry.

East European epicentre

The Polish government's Warsaw-based Institute of Electronic Materials Technology (ITME) was founded in 1979. It is focused mainly on silicon (including Ga doping for photovoltaic cells and radiation-resistant devices for space, or Sn doping for radiation detectors and oxygen-free products). This is especially convenient for MEMS manufacturing, mainly in the area of detector- and sensor-grade products. However, it also has compound semiconductor activities. Materials are produced by Czochralski, magnetic Czochralski, float-zone, and neutral transmutation doped processes, or in the epitaxy laboratory.

The institute's departments comprise: silicon single-crystal technology; compound semiconductor technology; oxide single-crystal technology; silicon and compound epitaxy; compound semiconductor materials applications; a laser laboratory; piezoelectronics; glass technology; ceramics, joints and composites; thick-film materials; chemical technology and environmental protection; high-purity material characterisation, microstructure research; and Mössbauer spectroscopy.

Figure 1. Poland's Institute of Electronic Materials Technology (ITME) in Warsaw, which is home to the spin-off companies Silicon Cemat, ComSeCore, and Epi-Lab.

ITME has also spun off three companies: Silicon Cemat, which produces silicon wafers and epiwafers, the III-Vs wafer manufacturer ComSeCore, and commercial epiwafer manufacturer Epi-Lab (Figure 1).

ComSeCor joint venture

In 2004 ITME established the joint venture ComSeCore with European commodity materials manufacturer Umicore. ComSeCore produces epi-ready InP and GaP wafers for the optoelectronics and electronics industry. It also supplies GaAs and InAs and distributes silicon wafers, III-V materials, and other crystal substrates for use in electronics.

Epi-ready InP and GaP substrates are obtained by synthesis of six-nines purity (6N) raw materials using the horizontal Bridgman method; single-crystal growth by a proprietary modified liquid-encapsulated Czochralski (LEC) growth technique; and then slicing, lapping, polishing, and epi-ready cleaning.

Epitaxial InP is obtained by MOCVD, and ComSeCor offers all sorts of epitaxial stacks for test and device purposes — from single-layer templates to device heterostructures.

In the Semiconductor Compounds Epitaxy Laboratory, growth of various structures has been developed from binary, ternary and quaternary GaAs-, InP- and GaN-based compounds. High-quality simple layers giving sophisticated structures that offer low background, high mobility, ideal uniformity and repeatability; atomic-scale growth rate, etc have been achieved, and deposited layers, such as superlattices, quantum wells and strained layers, are applied in electron device fabrication, i.e. transistors with a two dimensional

Figure 2. Wlodek Strupinski, president of Epi-Lab.

electron gas (2DEG), lasers, and others. Epi technology is also moving towards replacing traditional As and P gaseous sources with less toxic organic materials.

In the oxide single-crystal department, the lab has pioneered the growth and study of high-purity crystals of oxides and fluorides such as new laser hosts, piezo- and electro-optic materials and substrates for high-temperature thin-film superconductors. Here, the equipment includes furnaces for the synthesis of charges and the growth of single crystals of various types with seven Czochralski systems, two Bridgman furnaces, and eight autoclaves for hydrothermal method.

Poland's Epi-Lab

Inevitably, IEMT has grown to offer a combined commercial and R&D spin-off, Epi-Lab. Its president, Dr Wlodek Strupinski (Figure 2), has been involved in III-V materials technology for 25 years and has developed many MOCVD epitaxial structures that have gone into production.

Strupinski cooperates with international and domestic academic centers in III-V research projects. His core team comprises Dr Marek Wesolowski, a solid-state physicist responsible for the characterisation of epi-structures, modeling, and new concepts in epitaxial growth, and research engineer Dr Agata Jasik, who focuses on the epitaxial growth of strained InP-related epilayers for detectors and transistors.

Epi-Lab has three Aixtron MOCVD reactors. An Aixtron 200 system for GaAs- and InP-based epitaxy uses arsine (AsH_3) and phosphine (PH_3) precursors for group V elements, trimethylgallium (TMGa), trimethylindium (TMIn) and trimethyaluminium (TMAl) metalorganics for group III elements, and dimethylzinc (DMZn), silane (SiH_4) and carbon tetrabromide (CBr_4) for dopant elements. The system also has a halogen heating module and gas-foil susceptor rotation solution. Supplied hydrogen is highly purified by the serial system. A glove box with an nitrogen atmosphere allows oxygen-free packing and unpacking of wafers. Also, interest in dilute nitride materials has led to the purchase of a dimethylhydrazine (DMHy) source for the development of GaAs-based ~1.3mm-wavelength opto-electronic devices.

A second MOCVD reactor, an Aixtron 200S-RF system, grows GaN-based materials. It has ammonia (NH_3) for the group V element, TMGa, TMIn, TMAl metalorganics for the group III elements, and SiH_4 and bis-cyclopentadienyl magnesium (Cp_2Mg) for the dopant elements. It also has an RF heating module, nitrogen glove box, gas-foil planetary rotation, and *in-situ* characterisation by reflectometry. It is used mainly for growing nitrides on sapphire, and also grows AlGaN structures.

The third and newest reactor is designed for the growth of InP-based materials.

Characterisation includes the Accent RPM2000 photoluminescence mapping system (see Figure 3) for measuring spectra and maps at 330-1700nm, X-ray diffractometry (XRD), Hall measurement, and scanning electron microscopy.

Strupinski says that, as a natural development from its SiC bulk crystal growth, the lab is purchasing an Aixtron Epigress

Figure 3. Epi-Lab's product manager Piotr Caban using an Accent RPM2000 photoluminescence mapping system.

MOCVD system for the growth of SiC-based structures.

Epi-Lab also aims to develop compact epitaxy-support software. "This provides basic support for epitaxial growth of semiconductor materials and structures. The software was primarily designed to maintain the epitaxy of III-V ternaries and quaternaries, but it is also helpful in the wider area of structure and device stack evaluation." The first software module is directed to basic applications as a flow-correction calculator and bandgap calculator for a set of semiconductors. Flow-correction computing makes work with quaternaries efficient and easy. A second module concentrates on structures with quantum wells (QWs) by simulating the inter-band transitions, with a choice of pre-fixed barrier/well systems. There is also a module for direct QW analysis using photoluminescence, which can be useful for strained QWs. The third program targets structure characterisation using Bragg reflectors by estimating reflectance spectra.

The additional set of calculators makes epitaxy more convenient and effective. Also included are partial pressures and XRD reflex position calculators. The software is being developed to include new materials and functions needed in the future. The latest version, with modules for QW and reflector evaluation, is now available as a demonstration at www.epitaxyproject.com.

Epi-Lab's maximum production capacity is 10-20 epiwafers per week for each system. Commercial clients are offered 2-4 week delivery times. Most clients are academic centres, and Epi-lab also works with international partners on research projects. However, "there is an observable growth in private electronic companies", says Strupinski.

Infrared specialist Vigo

A bright light in the Polish compound semiconductor field is Warsaw-based Vigo Systems, which specialises in manufacturing infrared photodetectors and accessories (pre-amplifiers, cooler controllers, and IR systems) in integrated packages.

Poland's high-tech finance and facilities

Anyone considering the history of Poland quickly realizes that it is a great European crossroads. Poland has not been slow to appreciate its geographical value and its cosmopolitan inheritance (which is evident in its stunning architecture), and is currently working on seven special economic zones (SEZ) for business development.

In southern Poland, Bielsko-Biala (a former two-town region, combined in 1951) stresses its good road links to Warsaw, Berlin, Prague, Vienna, Bratislavia and Budapest, as well as its easy reach of the region's airports (see map).

Investors are offered up to 50% relief on investment costs or up to 50% of the two-year labour costs for any new jobs created. This is conditional on an original investment of €100,000, maintenance of fixed assets for at least five years, and maintenance of definite employment for at least five years, as well as obtaining permission to conduct business within the Katowice SEZ.

Investment has already flowed in from Italy, the USA, France, Holland, and the UK. Unemployment is close to 20% across Poland, but less than 10% in Bielsko-Biala.

The Beskidian Ark of Technology project — a partnership between the city, the university, and the Regional Development Agency — has funding of €2.875m (89% from the EU and 11% from the municipal budget). It has a modern three-storey office with 3600m^2 of conference and computer facilities and offices for at least 22 small enterprises that are expected to employ about 185 people in total.

Outsiders rate these moves highly. In a recent look at exchange-traded funds (ETFs), an S&P index strategist, Srikant Dash said he expects more ETF products to be focused on emerging markets as these become available, and that these will most likely feature the smaller 'new frontier' segments of these markets. Dash says that the next wave of innovation will likely be dedicated to emerging markets such as those in Eastern Europe, including Poland and the Czech Republic. "These economies are in the position that Korea and Taiwan were in 20 to 30 years ago," he says. "They're less correlated to the USA, and would provide the investor with the diversification that makes investing in the emerging markets so appealing."

Also, while China and the Far East may hold the record for low labour costs, in Poland the inclusive labour cost is €5/hr and the average working week is 42.6 hours. This compares with 39.1 hours in France, for example.

The government-owned company underwent a worker-management buyout in 1987 and downsized from a relatively large employer to a core team of 15. However, it has since grown to more than 50 staff. Next year it will move into a new, custom-designed facility. The development was financed mostly from Vigo's commercial production means, with very little government support.

For Vigo, the compound material of choice is HgCdTe (MCT), complemented by some use of ZnTe. Professor Jozef Piotrowski (who, in the late 1960s, demonstrated room-temperature operation of HgCdTe detectors at 10.6 µm and then introduced the first uncooled 10.6 µm HgCdTe photovoltaic detectors) explains that the company also worked with InGaAs, but found the material insufficiently flexible.

"With MCT you can get the same lattice constant for any material composition. So, we can grow any architectured device in three dimensions, with integration of opto- and photoelectric functions within one chip. The devices can be optimised for near-room-temperature operation at any wavelength in the short-, mid- and long-wavelength ranges of the infrared spectrum. And, in production, we can grow optical immersion lenses for our monolithic devices."

Uncooled 10.6 µm photodetectors were Vigo's earliest devices, mostly exported to the USA, e.g. the Los Alamos and Lawrence Livermore National Laboratories for nuclear applications.

"Initially," says Piotrowski, "we did some 90% export business with the US. Now that ratio is perhaps 60-70%, as the market has grown from the specialised military focus to include wider industrial and medical applications".

Vigo's manufacturing processes use isothermal vapour phase epitaxy (ISOVPE), modified by Vigo, complemented by an Aixtron MOCVD system producing MCT epilayers on 2" substrates.

Piotrowski says that this equipment allows very flexible production of both cooled and uncooled devices of any spectral wavelength range. Examples are detectors for warning systems that can detect radiation emitted by battle-field lasers.

"We specialise in high-temperature devices to get the best performance possible, and use simple two-stage (and sometimes three- or four-stage) peltier coolers, and normally two-stage controllers. Our devices are mostly used in gas analysers for various applications, including spectroscopic and Fourier transformer analysis equipment".

Vigo's photodetectors are used in industrial and medical applications. A major new market is quantum cascade laser-based systems. Among its portfolio of IR detectors, thermographic cameras, pre-amplifiers and thermo-electric cooler (TEC) controllers, this year Vigo has launched the type PCI- 2TE-13 photodetector, designed and optimised for Fourier transform infrared spectroscopy applications with a wide 1-13 µm spectral range and broad linear output range.

Vigo's latest development work is for new applications using quantum cascade lasers. It is also investigating European Union grants to further its specialist research and development work.

Software expertise

In the Krakow-Gdansk sector, an interesting network of electronic and technical companies has developed. Without any of the usual aid and assistance currently expected by start-ups, these have thrived by focusing on specific talents and particular markets.

A major success story is that of Evatronix, started as a self-funded, privately held, joint stock company in 1991 by Wojciech Sakowski and Wlodzimierz Wrona, electronic engineering graduates from the Silesian University of Technology (SUT) in Gliwice.

Evatronix develops intellectual property (IP) cores and offers electronic design services, as well as being a value-added reseller (VAR) of computer aided design (CAD) and electronic design automation (EDA) systems in Poland. It offers design tools from Australian-based Altium Ltd and is an Autodesk-authorised dealer and training centre for mechanical engineering.

The company's electronics design department was set up in 1997 in Gliwice to ease access to SUT's engineering graduates. It now employs about 35 full-time engineers and accommodates dozens of graduate interns. However, the new headquarters of the 50-strong company is now sited further south, in Bielsko Biala.

Evatronix's IP cores include legacy processor architectures based on the 8-bit Intel 8051; 16-bit Z80 cores; digital signal processor and numeric co-processor cores, with interface and communication controllers offering a variety of serial bus interfaces, audio transmissions, USB protocols, and data communication controllers. Miscellaneous cores include VGA, memory and data storage, peripherals with AMBA interfaces and encryption cores.

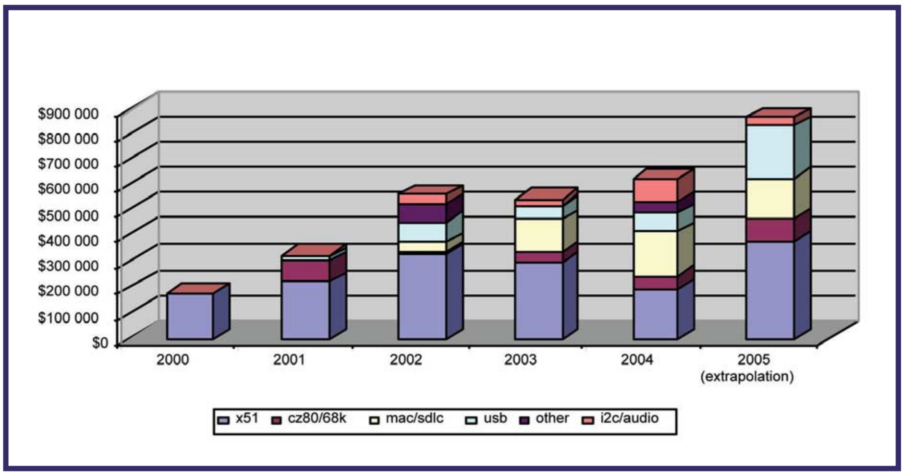

Figure 4. Growth in sales of Evatronics' IP cores.

On the cards

Cart Sp. z.o.o. (set up as Akita Sp z.o.o. in 1983, focused initially on PCBs offering single- and double-sided boards) chose in 1996 to diversify into producing plastic laminated cards, in cooperation with a Swiss plastic card manufacturer. It now makes 200,000 per month and hopes to double this capacity.

With a staff of 60 on both production lines, it either takes a customer's design and layout or provides in-house design and layout, for cards ranging from magnetic cards to full chip and transponder implanted units (in accordance with ISO 7810 and ISO 7811). Costs per 100 units are €1-10, depending on quantities required.

Applications for the read-only memory card range from access and work-time control to ski-lift tickets and electronic keys. EEPROM memory for reading and writing data on cards offers automatic payment collection, freeway payment, intelligent ID, university, parking, and loyalty cards. Clients include security companies, insurance and company service cards. While 70% of the business is Polish, clients also come from France, Germany, Cyprus, Belgium, and Ireland.

One of Cart's most intriguing products is for a series of gold printed rosary cards.

The IP cores are sold in the US and Asia through strategic partner CAST Inc, and in Europe through Evatronix's American distributor. Thanks to the cooperation with CAST, its value-added cores have been introduced into third-party IP programs run by companies such as Altera, Xilinx, Actel, Lattice, UMC, and Sonics.

Affiliation and partnership programs include Altera ACAP, Xilinx XPERTS. Evatronix is also a member of industrial consortia including ECSI, Design & Reuse, the Virtual Components Exchange, USB Implementers Forum and OCP-IP.

As a result, Evatronix has grown with core sales of just over $100,000 in 2000 to over $900,000 currently (see Figure 4).

Power source

Another Gliwice success is the electronic design company ZKE Merawex. Set up in 1989, it undertakes design of non-standard power supplies and assembly with through-hole and surface-mount technologies.

Products encompass 48 V_{DC} power stations, power supplies for voice evacuation systems, and other fire protection installations, as well as DC/DC converters and DC/AC inverters.

Merawex has evolved from documentation design in 1989 to original equipment manufacturer in 1991, short-series contract manufacture 1997, imported product sales in 2000, and original production of power supplies for fire protection in 2001 to its first major contract manufacturing of electromechanics in 2004.

"Work can range from series of a few thousand to smaller batches, and currently around 200 different types of devices," says marketing VP Witold Grabysz. "Major customers are companies working in telecoms, industry automation, fire protection systems, and energy."

Merawex has grown to €2.5m in annual revenues. It is planning a move to ambitious, newly renovated premises bought last year that will increase production floorspace from 640m² to 3700m². "We plan further organic growth, export, modernised manufacturing and reorganisation of work, new products, services and business models," says Grabysz. He acknowledges the challenges of "internal resistance to 'corporatisation', legal and linguistic barriers, an internal resistance to change, not to mention the perpetual 'war' for talent."

Meanwhile, Merawex is also cooperating with Poland's nanocentre in the Warsaw University of Technology's Faculty of Materials Science and Engineering on the application of soft magnetic nanomaterials in electronic devices operating at high temperature. Under the coordination of Professor Tadeusz Kulik, materials currently under investigation include permanent magnets and soft magnetic materials, intermetallics, Al-based structures, and nanocomposites.

In boards and assembly

A major player in Poland's electronics industry is the Techno Services Group, which was established in 1960 and turned into a public limited company in

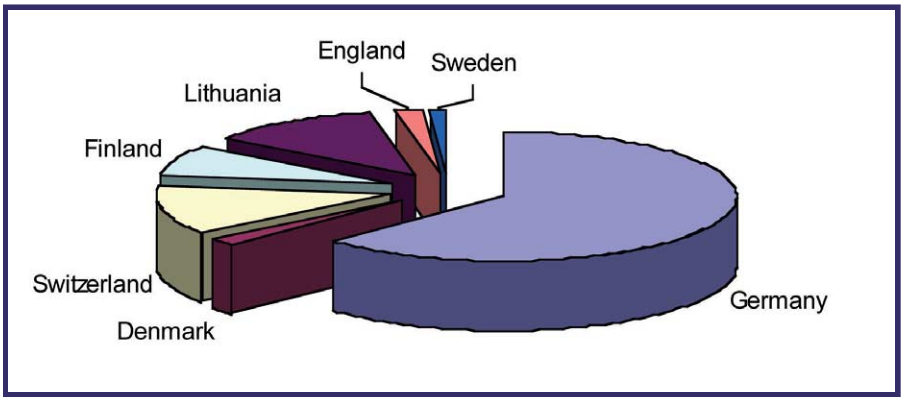

Figure 5. TechnoService's export markets.

1992. Its printed circuit board manufacturing in Gdansk and electronic assembly plants form two of the group's eight divisions. It offers double-sided and multilayer printed circuits, with a production potential of about 30,000 m^2 annually, allowing long runs or piece production.

The main advantages are flexibility and professional customer service. Automation of production processes, modern machines and constant control on each production step guarantee the high quality and production of high-density interconnect (HDI) circuits. Besides that, PCBs are subjected to 100% electrical testing using adapter testing machine, three-needle testing appliances and an AOI tester.

The plant can offer prototypes in as little as 24 hours, and production series in up to 10 days. Currently it produces lead-free technology, limiting the use of lead in the production of, among other things, printed circuit boards. It also puts a lot of emphasis on environmental protection. Other services are component purchasing, customer-specified testing, and such add-on services as PCB washing, varnishing, mechanical assembly and casing placements.

PCB customers include telecoms, security, computer cash registers, medical equipment, military and aviation, and industrial automation. Some 45% of production is exported (see Figure 5).

Also, an electronic assembly plant has operated since 1995. In 2001, 16 staff generated sales of €110,000; in 2005 over 60 staff will generate about €3m. President Jan Mioduski (Figure 6) notes that customers include 24 major Polish companies. Sales are divided between consumer electronics (33%); cash register devices (28%); ventilation (9%); telecoms (4%); and other (26%). Services comprise single- and double-sided SMT assembly for BGA, μBGA, flip chip to TSOP, QFP, PLCC, SO and TSSOP; through-hole assembly (both wave soldering and manual); lead-free production (currently being implemented; total lead free will be in place by 2006).

Figure 6. Jan Mioduski, general director of TechnoService.

Assembled packages are delivered in 10 working days, and it is intended to halve that. Capacity is 18,000 components per hour. This will be increased in October 2006 by a second line to 50,000 components per hour and, by 2007, with a third line to 100,000 components per hour.

Currently, the plant assembles 5m SMD and 1m PTH (plating through hole) components per month. A Technology Park is planned. This should increase capacity to 20m SMD and 5m PTH. R&D, in cooperation with centres such as the Technical University of Gdansk, will involve power supply design, microcontroller programming and software development, product certification, upgrades and repairs.

RF from a military base

In Poland's Aviation and Radio-Electronics Capital Group, Gdynia-based Radmor (established in 1947) is the major provider of HF/FM radio in Poland.

Its broad portfolio, which is AQAP 110 and ISO 9001 certified, includes military handheld, manpack, and vehicle radio stations: conventional and trunk communications; handheld mobile and stationary radio-phones, repeater, radio-modems and data transmission modules and accessories.

In 1996, Radmor won the contract to provide equipment to the Polish army and, while the company manufactures under license, it has also designed and manufactures its own product (the 3501) which has been exported to the Czech Republic, Slovakia and Lithuania. Capable of analogue, digital and data transmission, the 3501 complies with both the Polish WPN and US MIL specifications. As a small, light, personal handheld radio in a die-cast aluminium housing, it is sealed to dust, sand, water and humidity and withstands thermal shock, having a mean time before failure (MTBF) of some 16,000 hours. The 3501 can be used in vehicles as a tactical radio or stationary radio station. Now in its sixth version, the latest development is for software-defined radio, with frequencies of 20-520 MHz. Radmor sees it appealing to other markets, such as police, fire brigade, ambulance and other emergency services.

Poland's electronics industry is worth watching. There's an intriguing variety of compounds and a good basic infrastructure of companies providing highly qualified personnel. Alas, although most companies have young English-speaking translators, there is a language gap. However, www.thepolishtranslator.com can help.

Useful website addresses:

www.comsecore.com/index.html

www.itme.edu.pl/general.htm

www.epi-lab.com/index.html

www.epitaxyproject.com

www.vigo.com.pl/index.php?l=en

www.evatronix.pl

www.merawex.com.pl/www_en/index_sec_en.htm

www.technoservice.com.pl

www.radmore.com

www.cart.minskmaz.pl/galeria.htm

www.parp.gov.pl/en/innovation.php